DEFENCE R&D DÉFENSE

Radar Technology Forecast for Land Warfare

Guy J. Farley and S.M. Gauthier
Defence Research Establishment Ottawa

Defence R&D Canada
DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 2000-064
April 2000

National Defence Défense nationale

Canada

DEFENCE R&D DÉFENSE

Radar Technology Forecast for Land Warfare

Guy Farley
Countermeasures Techniques Group
Electronic Countermeasures Section

S.M. Gauthier
Maritime Radar Group
Surface Radar Section

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
DREO TM 2000-064
April 2000

Project
2KE11

ABSTRACT

The Canadian Army is planning a major update of land electronic warfare equipment in the next few years. In support of this acquisition there is a need to define the radar component of the future land electronic warfare threat. Part of the definition process involves predicting the technical characteristics of the array of radars that will be deployed by potential opponents. This report addresses this topic and has been written as one input to the Land Electronic Warfare Threat Target Array Study being coordinated by J2 Scientific and Technical Intelligence and sponsored by the Director of Land Requirements (DLR) and the Director of Land Command Systems Program Management (DLCSPM). In addition to considering the future trends in radar technologies and systems, this report also reviews the deployment of radar systems relevant to future land warfare. This treatment is divided into two parts: the ground-based and the airborne systems. When possible we give the following radar information: name, capability, specification, time of availability, the list of the countries developing and acquiring it. Of the ground-based radars, we specifically consider the following: weapons locating and shell tracking, battlefield surveillance, meteorological, surface-to-air weapons, ground vehicle self-protection, target acquisition systems for main battle tanks, and subsurface object detection.

RÉSUMÉ

L'Armée Canadienne est en train de préparé une amélioration majeure des ses équipements de guerre électronique pour les prochaines années. En support de cette acquisition, il y a un besoin de définir les composantes radars de la menace future de la guerre électronique de terre. Une partie de ce processus de définition exige la prédiction des caractéristiques des réseaux radars qui seront déployés par des ennemis potentiels. Ce rapport aborde ce sujet et a été écris pour supporter l'étude de la matrice des menaces de guerre électronique terrestre qui est coordonnée par le directeur du renseignement scientifique et technique (J2 STI) et supportée par le directeur des besoins terrestre (DLR) et le directeur de la gestion du programme des systèmes de commande terrestres (DLCSPM). En plus d'examiner les tendances futures des technologies et des systèmes de radar, ce rapport examine aussi le déploiement de systèmes radar pertinents à la guerre terrestre future. Ce sujet est traité en deux parties: les systèmes terrestres et de l'air. Quand c'est possible, l'information suivante est fournie: nom, capacité, date de déploiement, la liste des pays qui sont en train de le développer ou de l'acquérir. Pour les radars terrestres, on considère spécifiquement les applications suivantes: pour traquer des obus et le repérage des armes, la surveillance des champs de batailles, météorologie, les armes sol-air, la protection des véhicules terrestres, les systèmes d'acquisition de cibles pour les char d'assauts, et la détection des cible sous la surface.

EXECUTIVE SUMMARY

Radar is a sensor capable of detecting and locating targets at long range in all weather conditions, day or night. It will remain the main sensor in air defense networks, although increasingly in combination with other sensors such as infrared-red (IR) and electro-optics (EO). During the next decade, the performance of radar systems will continue to increase rapidly. They will be able to detect low observable targets at all altitudes even in presence of advanced ECM. Radar target discrimination will increase significantly, and target identification or recognition will become possible. During the next decade, radar technology will benefit from advances in analog-to-digital converter technology, artificial intelligence and digital signal processing hardware and algorithms. Emerging radar technology such as laser radar and high-power nanosecond radars will also start to appear. By the turn of the century, electronic scanned arrays with ultra low sidelobes will become readily available at attractive cost. Radar systems will also become ever more difficult to intercept, and resistant to ECM.

In all facets of battlefield sensor development, there is a continuing struggle to increase performance while maintaining a low level of detectability at a reasonable cost. Some performance enhancing techniques have inherent Low Probability of Intercept (LPI) attributes or give the radar a degree of Anti-Jam (AJ) or Electronic Protection (EP) capability. Other improvements are designed for the sole purpose of obtaining one or more of these attributes. Radar techniques of concern include: phase or frequency modulation, multi-frequency, advanced antennas, and target recognition.

In addition to these radar techniques, certain radar systems are also of concern for the future. We can list the following radar systems of concern: Synthetic Aperture Radars (SAR), Ultra-WideBand (UWB), high-power nanosecond, millimeter wave, bistatic and multistatic, laser, and Over-The-Horizon Radars (OTHR). The problems presented to the Intelligence and Electronic Warfare (IEW) community by SAR are their incredibly diverse parameters. Operating frequencies can range from High Frequency (HF) to Millimeter Wave (MMW), and they can employ multiple frequencies in different bands.

UWB radars are implemented through frequency modulation/agility or through direct transmission of extremely short pulses. The latter type is called impulse radar or nanosecond radars. Conventional heterodyne receivers would probably be unable to detect those types of radar, which are likely to be deployed by 2020.

The high cost of relativistic High-Power Microwave (HPM) technology will restrain its proliferation to few countries, but the commercial availability of cheap high-power semiconductor switches would mean impulse radars could proliferate quickly.

Progress in MMW radar R&D will make it more attractive. R&D efforts in MMW seekers have concentrated on the development of advanced seekers for anti-tank missiles. Typical MMW seekers are FMCW with a bandwidth of 500 MHz and a range resolution of 30 centimeters. These advanced anti-tank missiles will operate in the 35 GHz and 95 GHz MMW windows. Rather than supplanting microwave radar, laser radar opens new capabilities that exploit the great shift in wavelength.

There is now considerable research on development of multistatic radar throughout the world and this could represent a significant threat to our platforms. OTHR are also the subject of considerable attention worldwide, and can significantly enhance both defensive and offensive capabilities. Future deployment of Surface-Wave OTHRs (SWOTHR) can turn out to be a serious threat to western warships. Foreign development of sky wave OTHR should also continue to be closely monitored especially redeployable OTHR. Bi-static or multi-static radars using commercial signals such as TV or FM radio signals also deserve mention.

The Canadian Army is planning a major update of land electronic warfare equipment in the next few years. In support of this acquisition there is a need to define the radar component of the future land electronic warfare threat. Part of the definition process involves predicting the technical characteristics of the array of radars that will be deployed by potential opponents. This report documents the predicted radar technical characteristics. It has been written as an input to the Land Electronic Warfare Threat Target Array Study being coordinated by J2 Scientific and Technical Intelligence and sponsored by the Directors of Land Requirements (DLR) and Land Command Systems Program Management (DLCSPM).

Authors, Farley, G., Gauthier, S.M., Radar technology forecast for land warfare, Defence Research Establishment Ottawa, DREO TM 2000-064, March 2000.

SOMMAIRE

Les radars sont capables de détecter et localiser des cibles éloignées dans n'importe quelles conditions météorologiques, le jour ou la nuit. Ils demeureront le détecteur principal dans les réseaux de défense aérienne mais seront de plus en plus intégrés avec d'autres types de détecteurs tel qu'infrarouge et électro-optique. Pendant la décennie suivante, la performance des systèmes radars va continuer a s'améliorer rapidement. Ils seront capables de détecter des cibles furtives volant à basse ou haute altitude et cela même en présence de coutre mesures électroniques. La résolution des radars va beaucoup s'améliorer et l'identification des cibles deviendra possible. Durant la prochaine décennie, l'avancement majeur dans le développement des radars sera accompli à travers le traitement des signaux. L'intelligence artificielle et les algorithmes sophistiqués vont faire leurs chemins dans les systèmes déployés. Les nouvelles technologies radar tel que le radar laser et les radars nanoseconde à haute puissance vont aussi commencer à apparaître. Au tournant du siècle, les réseaux à balayage électronique avec de très faibles lobes secondaires deviendrons rapidement disponible à des coûts intéressant. Les systèmes radars deviendront aussi beaucoup plus difficile a intercepter et résistant aux contre mesures électroniques.

Dans le développement de détecteur militaire, il y a une bataille continuelle pour augmenter les performances et maintenir un niveau de detectabilité très faible à un coût raisonnable. Quelques techniques pour améliorer les performance radar fournissent aussi une faible probabilité de détection ou fournit au radar un degré de résistance aux brouillage électronique ou de protection électronique. Certaines améliorations de performance sont effectuées pour le seul but d'obtenir un ou plusieurs de ces attributs. Les techniques radar d'intérêt inclus : la modulation par phase ou fréquence, les radars à fréquences multiples, les antennes avancées, et l'identification des cibles radars.

En plus de ces techniques radars, certains systèmes radars sont aussi d'intérêt pour le future. Ceux-ci inclus, les radars à ouverture synthétiques (ROS), les radar à très large bande, les radars nanoseconde à haute puissance, les radars à onde millimétrique, les radars bistatiques et multistatiques, les radars lasers, et les radars décamétrique à onde de surface (RDOS). Les problèmes liés aux ROSs pour la communauté du renseignement et de la guerre électronique sont leur incroyable diversitées de paramètres radar. Leurs fréquences d'opérations peuvent varier des bandes décamétrique aux ondes millimétrique. Ils peuvent aussi employer plusieurs fréquences dans des bandes différentes. En fait, la technologie des radars à très large bande est idéale pour les ROS, lesquels peuvent maintenant opérer avec une bande de fréquence instantanée de plus de 500 MHz.

De très larges bandes de fréquence peuvent être obtenues par une modulation en fréquence ou en transmettant directement de très courte pulses. Ce dernier type est appelé radar à impulsion ou nanoseconde radar. Les récepteurs hétérodynes conventionnels ne peuvent pas détecter les transmissions de ces radars lesquels seront probablement déployés d'ici 2020. Le coût élevé des sources micro-onde à haute puissance va cependant limiter leur déploiement à quelque pays. Cependant, les sources à impulsion micro-onde semiconducteur de moindre puissance seront moins dispendieuses. Ces radars à impulsion de moindre puissance vont être intégrer plus rapidement dans les équipements standard militaires.

La grande quantité de recherche présentement effectuée dans la technologie des ondes millimétriques va se continuer pour plusieurs années et vont rendre les radasr à onde millimétrique plus intéressant Les plus grands efforts de recherche sont dans le développement des autodirecteurs de missiles lesquels ont produit des autodirecteurs sophistiqués pour les missiles antichars d'assauts. Des autodirecteurs millimétriques typiques utilisent une modulation de fréquence avec une bande de fréquence de 500 MHz et ont une résolution de 30cm. Ces missiles antichars d'assauts vont opérer dans les bandes de 35 GHz ou 94 GHz. Plutôt que de remplacé les radars micro-onde, les radars lasers offre de nouvelles capacités.

Il y a maintenant beaucoup de recherche effectuée dans le développement de radars multistatiques à travers le monde et ceci pourrait représenter une menace considérable pour nos plates-formes militaires. Les RDOS sont aussi le sujet d'attention considérable et peuvent améliorer de beaucoup les capacités militaires défensive et offensive. Les futures RDOS peuvent s'avérer être une menace considérable pour les navires de guerre de l'ouest. Les développements des radars décamétrique à onde ionosphérique devraient aussi continuer d'être surveillés de près, en particulier ceux qui sont transportable.

L'Armée Canadienne est en train de préparé une amélioration majeure des ses équipements de guerre électronique pour les prochaines années. En support de cette acquisition, il y a un besoin de définir les composantes radars de la menace future de la guerre électronique de terre. Une partie de ce processus de définition exige la prédiction des caractéristiques des réseaux radars qui seront déployés par des ennemis potentiels. Ce rapport documente les techniques radars prédites. Il a été écris pour supporter l'étude de la matrice des menaces de guerre électronique terrestre et coordonnée par le directeur du renseignement scientifique et technique (J2 STI) et supportée par le directeur des besoins terrestre (DLR) et le directeur de la gestion du programme des systèmes de commande terrestres (DLCSPM).

Authors, Farley, G , Gauthier, S.M., Radar technology forecast for land warfare, Defence Research Establishment Ottawa, DREO TM 2000-064, March 2000.

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 RADAR TECHNIQUES 2

2.1 WAVEFORM DESIGN, MODULATION, AND CODING 2
2.1.1 Continuous-Wave Radar 2
2.1.2 Pulse Compression 2
2.2 MULTI-FREQUENCY SYSTEMS 3
2.2.1 Frequency Diversity 3
2.2.2 Frequency Deception 4
2.2.3 Frequency Agility 4
2.3 ADVANCED ANTENNAS 4
2.3.1 Low Sidelobe Antennas 4
2.3.2 Antenna Phased-Array 5
2.4 RADAR TARGET RECOGNITION 6

3.0 RADAR SYSTEMS 6

3.1 SYNTHETIC APERTURE RADAR 6
3.2 ULTRA-WIDE BAND RADARS 7
3.3 HIGH-POWER NANOSECOND RADARS 7
3.3.1 X-Band Super-Short Radars 8
3.3.2 Impulse Radars 8
3.4 MILLIMETER WAVE 8
3.5 ANTI-TANK MISSILES GUIDANCE 9
3.6 FIRE CONTROL - TARGET TRACKING 10
3.7 BISTATIC AND MULTISTATIC RADAR 10
3.8 LASER 10
3.9 OVER-THE-HORIZON RADAR 11

4.0 DEPLOYMENT OF SYSTEMS 12

4.1 GROUND-BASED 12
4.2 WEAPONS LOCATING AND SHELL TRACKING 13
4.3 BATTLEFIELD SURVEILLANCE 14
4.4 METEOROLOGICAL 15
4.5 SURFACE-TO-AIR WEAPONS [15] 15
4.5.1 Heavy IR SAM 15
4.5.2 Short-Range SAMs 15
4.5.3 Medium-Range SAMs 17
4.5.4 Long-Range SAM/ATBM Systems 18
4.5.5 Anti-Aircraft Artillery 19
4.5.6 Hybrid Systems 20

4.6 AIR SURVEILLANCE 20
4.7 GROUND VEHICLE SELF-PROTECTION 23
4.8 TARGET ACQUISITION SYSTEMS FOR MAIN BATTLE TANKS 23
4.9 SUBSURFACE OBJECT DETECTION 24
4.10 AIRBORNE 24
4.10.1 Battlefield Surveillance *24*

5.0 CONCLUSIONS 26

6.0 LIST OF ABBREVIATIONS 27

7.0 REFERENCES 29

LIST OF TABLES

Table 1: Definition of Antenna Sidelobe Levels 5
Table 2: MMW Radar Advantages 9
Table 3: HARD Parametric Characteristics 22
Table 4: STARTLE Specifications 23
Table 5: Typical GPR Parametric 24

RADAR TECHNOLOGY FORECAST FOR LAND WARFARE

1.0 INTRODUCTION

Radar is a sensor capable of detecting and locating targets at long range in all weather conditions, day or night. It will remain the main sensor in air defense networks, although increasingly in combination with other sensors such as infrared-red (IR) and electro-optics (EO). During the next decade, the performance of radar systems will continue to increase rapidly. They will be able to detect low observable targets at all altitudes even in presence of advanced ECM. Radar target discrimination will increase significantly, and target identification or recognition will become possible. During the next decade, radar technology will benefit from advances in analog-to-digital converter technology, artificial intelligence and digital signal processing hardware and algorithms. Emerging radar technology such as laser radar, high-power nanosecond radars will also start to appear. By the turn of the century, electronic scanned arrays with ultra low sidelobes will become readily available at attractive cost. Radar systems will also become ever more difficult to intercept, and resistant to ECM.

A drawback of radar systems from a military perspective is that they have to transmit electromagnetic energy. This makes them quite vulnerable to enemy intercept and exploitation. In fact, relatively modest intercept receivers can detect most radar emissions and thereby provide useful information. Once intercepted, the enemy could attack the radar site with anti-radiation missiles (ARM) or launch an electronic attack (EA). This can have devastating impact as seen during the gulf war, when ARMs simultaneously hit Iraqi key radar sites. They never recovered from this severe attack. Radar designers have no choice but to reduce the detectability of radar emissions. The denial of signal interception would protect radars from most known threats. This will not only increase survivability, but also make surprise attacks possible. Indeed, the enemy will not be aware that it is being tracked and soon to be engaged by high speed missiles. Besides reducing radar emission detectability, radar designers must also increase resistance to ECM. Otherwise, the radar system and associated weapons could become questionable assets in real conflicts.

The operational concept of low probability of intercept (LPI) radar is to reduce the exposure to intercept and/or making the interpretation and exploitation of the observed signals more difficult. This can be done by:

- transmitting only the power needed to detect a target.
- directing the energy precisely towards the target through very narrow beamwidth and low sidelobe levels. The latter is very important since it reduces the number of pulses observed by an EW receiver and makes the radar difficult to detect outside the scan pattern covered by the radar. It also reduces the vulnerability to deception jamming techniques, which depend on injecting signals into the radar antenna sidelobes.
- Using frequency agile signals. If a narrowband EW receiver is used, only a small fraction of the transmitted pulses will be detected and it will be more difficult to determine parameters of the radar signal, such as pulse repetition interval, needed to identify the radar. Also, the effectiveness of a simple fixed frequency narrowband jammer will be substantially reduced.
- Using complex waveforms to reduce detectability by extending the duty cycle of the

transmitted signal and thereby allowing the peak power to be reduced while maintaining the average power. Conventional radar EW receivers are optimized for the detection of short duration pulses, they are poorly matched to this type of signal.

2.0 RADAR TECHNIQUES

The radar designer must make many trade-offs to obtain a radar design that meets the specific application requirements. There are continuing demands to improve performance and reduce size and cost. At the same time, the vulnerability to electronic intercept and countermeasures is an issue. This often presents a dichotomy. For example, transmitting more power increases the detection range and jamming resistance, but also increases the range at which a given probability of intercept can be achieved by an EW system. Sometimes there is not a clear line that defines a technique as either a performance enhancer or a Low Probability of Intercept (LPI) enhancer for the radar For example, complex waveforms techniques not only reduce detectability, but also enhance clutter rejection and target measurements. Another advantage is that the reduced peak power facilitates the use of solid state transmitters. Conversely, these techniques are not free to the radar designer; they require extra circuitry and processing power. Furthermore, a sophisticated EW receiver may be able to exploit them to reliably identify the specific type of radar associated with the signal.

2.1 Waveform Design, Modulation, And Coding

2.1.1 Continuous-Wave Radar

A resurgent area of radar technology is the use of low power CW radar. These radars are usually modulated in frequency or phase to measure the target range. MTI and MTD processing techniques can easily be implemented in these radars. FMCW or PMCW radars are becoming increasingly popular, in part due to their inherent LPI attributes, which make them virtually undetectable by conventional ESM receivers. Indeed, most EW receivers are optimized for detection of high peak power and low duty cycle (i.e., short duration) pulses. CW radars were largely abandoned in favor of pulse radar systems many years ago due to technical limitations that severely limited their capabilities. CW radars are attractive for implementation with solid-state circuit technology since the low peak power requirements are easily satisfied.

2.1.2 Pulse Compression

Pulse compression is used to improve range resolution, and/or reduce peak power requirements. The latter has the additional benefits that the detectability by conventional EW receivers and the susceptibility to non-coherent jamming are reduced. Common techniques for compression are the use of frequency or phase modulation.

A major issue in the design of pulse compression waveforms is to achieve a compressed pulse that has low time sidelobes. Linear FM on the pulse has been the modulation of choice for radars that require very high range resolution. Range-Doppler coupling occurs in the detection processing of this waveform, but this is unimportant in many applications and the processing can be quite simple. Consequently, this waveform is attractive when velocity information is not needed. Typical applications include ground mapping and detection of submarine periscopes. Some of these radars

are currently operating with a bandwidth of about 500 MHz [1] Even a higher bandwidth is theoretically possible using digital signal generation techniques. Nonlinear FM has also become very popular. Common codes for phase modulation are Barker, Gold (perfect) codes, and linear recursive (pseudo-noise) sequences (LRS). The Barker code can be considered a discrete approximation to non-linear FM.

A new economical and accurate method for generating chirp waveforms has been developed based on recent advances in digital technology. Known as Direct Digital Synthesis (DDS), this technique can be used to generate various waveforms. Presently FM waveforms having a maximum bandwidth of just less than 400 MHz can be generated using high speed ECL or GaAs technology [2]. These high bandwidth FMOP radars will be widely used in military radars for applications such as high-resolution ground mapping and battlefield surveillance applications where target recognition is a requirement.

For a wideband EW receivers (crystal video, IFM, etc.) the use of the modulation to increase the bandwidth is not an issue. It is the ability to spread the signal energy over time (i.e. to reduce the peak power) that is important to reduce detectability. Indeed, these receivers are optimized for detection of high peak power and low duty cycle waveforms. EW receivers, as opposed to radar receivers, do not have *a priori* knowledge of the transmitted waveform and therefore cannot benefit from optimal (matched filter) detection techniques. Conventional EW receivers are designed for detecting pulse waveforms having duration on the order of 0.1 microsecond and are poorly matched to the detection of signals having substantially larger duration.

High duty cycle waveforms using FM or pseudo noise phase modulation can have very good LPI characteristics, especially in applications where relatively short range is required..

2.2 Multi-Frequency Systems

2.2.1 Frequency Diversity

Frequency diversity technique involves the wide dispersion of frequencies of either a single radar or multiple radars within a system configuration. The technique is effective for many of the same reasons as frequency agility. The implementation is different and the necessary bandwidth is much wider with frequency diversity. An example of such a system is a short range anti-aircraft artillery (AAA) fire control system. Many Western systems of this type employ a target acquisition radar that operates in D-band, while the associated tracking radar operates in I-band and/or K-band. The two radars can be separately optimized for their respective functions (e.g., the tracking radar can have a very narrow beamwidth, which is useful for tracking a target in a clutter environment). An example of diversity within a single radar is the multi-band synthetic aperture radars (SAR) which exploit the changing target aspects as seen by different frequencies. A typical system could transmit in D, E/F, and I-band simultaneously. While this multi-frequency operation was not intended as an LPI technique, it has inherent EP features, which will aid in its survivability on the electronic battlefield.

The overall intent of frequency diversity as an intentional EP technique is to force a hostile Electronic Attack (EA) system to either attempt to jam all related frequencies, which results in less

jamming power, or to choose the radar emission deemed as the greatest threat. In some cases, particularly where the second radar is at millimeter wavelengths, many jammers will not have sufficient frequency coverage. An incidental benefit is that a Radar EW system may be confused into thinking there are many radars instead of one or a few radars (i.e. more complex de-interleaving problem).

2.2.2 Frequency Deception

Some modern radar also transmit extraneous frequencies to attempt to confuse the ESM system as a low probability of exploitation (LPE) technique to forestall/mitigate attempts at jamming. Also, since it is well known that many conventional ESM systems cannot accurately process simultaneous pulses, this technique also affects the effectiveness of ESM systems using IFM receivers.

2.2.3 Frequency Agility

Frequency agility (FA) refers to the radar's ability to change frequency rapidly. FA is commonly used as an EP feature to force a jammer into a barrage-jamming mode. Tracking radars can also use FA to reduce the frequency dependent effects of target glint, scintillation, and multipath [3]. If the carrier frequency of the radar is controlled electronically, the hop frequency sequence can be made random over the radar's entire tuning range.

FA emitters pose a serious problem for intelligence and electronic warfare (IEW) equipment. Pulse-to-pulse FA complicates the task of the electronic warfare (EW) system designer in implementing pulse deinterleaving algorithms to associate observed pulses with individual radars. If additional techniques such as pulse repetition agility are used by the radar, this task can be very difficult. Considerable sophistication may be required, including both in the processing of the signal reports generated by the EW receiver and in the measurement of additional signal parameters and existing ones with greater accuracy.

Nearly all-modern military radars employ FA as an EP feature. Frequency agile radars will continue to present IEW designers with a challenge. As transmitter and antenna technologies progress, allowing for wider bandwidth, EW receivers will be even further taxed to process these emissions.

2.3 Advanced Antennas

2.3.1 Low Sidelobe Antennas

An aspect incorporated into any good LPI design is the use of low-sidelobe antennas, which protect against interception through the radar antenna's sidelobes. This is particularly important in reducing the vulnerability of radars to ARM-type missiles. The geometry of ARM-type engagements is such that the detection of radar emissions through the sidelobes is necessary to provide timely guidance information. This is particularly true for scanning radars whose main beams continuously move through the surveillance volume. Also, low sidelobe antennas reduce the effectiveness of jamming techniques that depend on injecting signals into the radar antenna sidelobes. The limits on antenna sidelobes are defined in Table1.

Table 1: Definition of Antenna Sidelobe Levels

Performance	Relative Level	Average Level
Ordinary	-13 to -30 dB	0 to -5 dBi
Low	-30 to -40 dB	-5 to -20 dBi
Ultra-Low	Below -40 dB	Below -20 dBi

Low-sidelobe antennas have become an increasingly valuable asset in the radar world especially in those radars designed to operate in high clutter and/or dense EA environments. In [1] it is believed that by the year 2010 most tactical radars will employ low to ultra-low sidelobe antenna technology.

2.3.2 Antenna Phased-Array

Since the 1970's, phased arrays that electronically steer their beams in elevation and azimuth have come into their own. Large phased arrays have been constructed and electronically steered phased arrays have received wide acceptance in several applications. Advantages include:

- ability to track multiple targets with the same array;
- elimination of the slew rate limitations of mechanically scanned antennas;
- suitability for achieving high power by using many solid state transmitter modules (active arrays).

The trend toward the use of these antennas can be expected to continue.

An important advantage of electronic scanned phased array antenna is the capability to direct the signal energy where it is needed. Radars can take advantage of this to implement a wide range of scan patterns, including pseudo-random scanning patterns. Track while scan radar modes can be realized by using a portion of the pulses to scan for new targets while the remaining pulses are used to track one or more targets. This complicates the task of an EW system since it may no longer be possible to determine the radar's scan pattern or to determine if the radar is tracking the host platform of the EW system. Electronically steered phased array antennas can be used in combination with other LPI techniques.

A large amount of R&D on phased arrays is dedicated to active and conformal arrays. Active arrays are arrays where each element is an active transmit/receive module. The present active array manufacturing technology makes for a bulky expensive product. A typical array with 2000 transmit/receive (T/R) elements can weigh several hundred pounds and have a depth of at least 12 inches. Although progress has been made in recent years, the technology remains very expensive. Since the array is quite heavy and does not have a low profile, it cannot be easily conformed to the skin of an aircraft, be placed on the mast of a ship, or be deployed on vehicles that have limited space.

Conformal arrays are of particular relevance to aircraft since the radar antenna(s) can be flexibly located without incurring aerodynamic penalties. Hughes Aircraft has pioneered a new technology for the packaging and assembly of an active array that will provide a substantial cost saving while

delivering a lightweight, low-profile assembly. The new array will have a profile of less than two inches in thickness and a weight less than 75 pounds for a 2000 element active array. The new technology will allow active arrays to be used in aircraft, ground-based, missile, ship, or spacecraft radar application.

The addition of photonics to this new manufacturing process has allowed for wideband beam steering. True-Time Delay (TTD) beam steering uses opto-electronic components to achieve wide instantaneous bandwidth wanted for the next generation shared aperture active arrays. TTD can be used for both wide bandwidth and wide instantaneous bandwidth operation with no setting change. This feature offers a distinct advantage for many radar applications [4].

With further progress, the high prices associated with phased arrays will decrease resulting in wide scale proliferation of these antennas in applications where their usage was previously not possible.

2.4 Radar Target Recognition

A new generation of radar systems with the capability to identify automatically aerospace targets is currently in development. The capability of quickly identifying targets from their radar returns alone would change warfare scenarios. This would definitively enhance the effectiveness of both offensive and defensive operations under all weather conditions, day or night. Radar target recognition would provide a battlefield awareness that had never been possible in the past, and affect almost every aspect of command and control. Commanders would know immediately who is coming, and would be ready to repel any attacks. Radar target recognition would also provide a much better control of long-range weapons. For example, threats could be identified and engaged at the maximum lethal range of the available weapons. There would be no need to wait for visual identification before engagement. It would also reduce civilian and military losses from our own fire. Some think that during the next decade, radar target identification will become the norm of advanced radars.

3.0 RADAR SYSTEMS

3.1 Synthetic Aperture Radar

An area of significant interest and development is that of synthetic aperture radar (SAR). SARs are ideal for many military applications of which ground mapping for target detection and identification purposes is preeminent. Rapid advances in analog-to-digital converters, digital signal processing algorithms and digital processor hardware has made it possible to accomplish the SAR function on board an aircraft in real-time. This capability has made SAR a common mode in newer generation multi-mode airborne intercept (AI) radars. SAR will probably be a requirement in future AI radars.

The problems presented to the IEW community by SARs are their incredibly diverse parameters Operating frequencies can range anywhere from high frequency (HF) to millimeter wave (MMW). SARs can and do employ multiple frequencies in different bands to optimize the frequency dependent glint and backscatter characteristics of the targets. SARs now operate with an instantaneous bandwidth of up to 500 MHz for high range resolution.

3.2 Ultra-Wide Band Radars

Ultra-WideBand (UWB) radars are defined as having an instantaneous bandwidth of at least 25 percent of the center frequency. UWB radars can be implemented through frequency modulation/agility or through direct transmission of extremely short pulses. The latter type is called impulse radar, and will be covered under the section on high-power nanosecond Radars. Sweden has developed an UWB airborne SAR radar operating in the frequency range 20-90 MHz. The use of VHF frequencies provides a good capability to penetrate foliage and the wide bandwidth yields a resolution of a few meters.

3.3 High-Power Nanosecond Radars

A new generation of radars, coined high-power nanosecond (ns) radars, is now emerging from both Eastern and Western laboratories. These radars transmit high power pulses of extremely short duration, either at x-band or without a carrier. Typically, the duration ranges from less than a nanosecond to a few nanoseconds. This provides a high resolution in range (centimeters) without any sophisticated signal processing. Pulse compression is an alternative method to get high resolution in range. However, compressed pulses suffer from time sidelobes, and are limited in the achievable compression. Transmitting short pulses of high peak power directly is much simpler in concept. (This is now even feasible for long-range radars as shown by U.S and Russian experimental systems that transmit GW peak power.) However, this has only been possible lately due to the rapid advances in high-power nanosecond technology.

Centimeter range resolution significantly enhances the performance of radars by increasing clutter rejection and reducing multipath effects. This makes them of interest for detection and tracking of low flying and low-observable targets embedded in strong clutter. Examples of such targets include sea-skimming missiles, helicopters, cruise missiles, etc. Key applications also include target classification and identification based on the range profile. Super-Short Pulse Radars also have a high-speed resolution since they can measure it directly as the target moves from one range resolution cell to another. No blind speed results since the Doppler effect is not used. Short pulse radars can be carrier frequency modulated as in conventional systems, or carrier free. The latter type is called impulse radar, video pulse radar, impact radar, etc. Use of impulse signals provides a high resolution not only in range and speed, but also in angle. Furthermore, impulse signals suffer practically no attenuation since frequency spectrum goes from 100 MHz to 10 GHz. This makes them attractive for weapon guidance (land-based fire-control radar in anti-missile defense systems). Impulse signals also enhance detection of stealth targets due to transient effects and low frequency spectral content.

The bandwidth of high-power ns radar goes from hundreds of MHz to GHz depending on the pulse length. Short pulse radars have LPI characteristics since conventional EW receivers are poorly matched to these waveforms. Impulse radars are of particular concern since they generate pulses without a carrier frequency. As a result, their frequency spectrum ranges from near DC to GHz Deployment of impulse radars could represent a significant threat to our platforms. We have to prepare ourselves to face this developing threat. There might be a similar threat for Super-Short Pulse Radars (SSPR) operating with a carrier frequency because of the narrow bandwidth of

conventional receivers.

3.3.1 X-Band Super-Short Radars

In 1985, Russia had already tested a high-power microwave radar prototype on the Kulyman test range on the bank of the Ob River near Tomsk [5]. This radar transmits pulses of five nanoseconds, at 10 GHz, with a peak power of half a Gigawatt at a rate of 100 pps. The receiver is of heterodyne type with a bandwidth of 210 MHz, and an intermediate frequency of 2 GHz. During testing, this system shows an enhanced clutter rejection capability. Processing is very simple, pulse subtraction, and there is no blind speed. They see this system as best against low flying targets such as helicopters and sea skimming missiles. Recently, an experimental S-band high-power nanosecond radar has also been developed by Russia [6]. However, we have little information on this system. Today, transmitters using relativistic beams can produce ns GW peak power at PRFs of 50 Hz to 1000 Hz. A typical bandwidth is a few hundreds of MHz. Taking a conservative development period of fifteen years, these Russian systems are likely to be deployed by 2020. However, the high cost of the relativistic High-Power Microwave (HPM) technology will restrain its proliferation to few countries.

3.3.2 Impulse Radars

Impulse radar is coming quickly due to technology advance in GaAs semiconductor switches [7]. Several experimental prototypes of high-power impulse radars have been developed, including electronically steerable arrays. Impulse radars can also be based on pulse power forming line techniques [8]. However, high-power semiconductors sources are the most promising in the short term because they are cheaper, more compact, lower power consuming, and more mature. Semiconductor sources have been used in the development of a steerable array antenna that can produce GW peak power pulses [9]. Typical impulse radars developed have the following parameters: pulse length of 600 picosecond (ps), rise time of 200 ps, PRF of 10 kHz, and bandwidth of several GHz. Russia is not as advanced as the US in development of impulse radars but is closely following in their footsteps. By 1994, they had developed experimental prototypes of ns and sub-ns impulse radars using the pulse power line technique [10], [11]. The PRF ranges from 50 Hz to 100 Hz. Laboratory testing did occur and the radars behaved as expected. The next stage is fi[illegible]d-testing. Russia has also been working on a semiconductor GaAs impulse radar with the [illegible]ollowing parameters: pulse length of 3ns, PRF of 80 kHz [12]. Rapid advances in high-power GaAs semiconductor and pulse power sources are also occurring in many third world countries that are working on impulse radars. Commercial availability of cheap high-power semiconductor switches means those impulse radars will proliferate quickly and become standard equipment of any military power.

3.4 Millimeter Wave

Considerable research has been going on developing MMW radar technology, and several Ka-band systems have already been deployed. MMW frequencies range from 30 to 300 GHz. The atmospheric attenuation goes through an increasing series of peaks and minima as the frequency increases. Although MMW radars usually operate in the minima regions called transmissions

windows, centered around 35, 95, 140, and 220 GHz, propagation losses are substantial and further increase during rainfall. As a result, the range of MMW radars is usually limited to a short distance, 5 to 10 km. Extensive commercial research into MMW waveforms, antennas, processing, and components is currently underway, and will continue. This research will improve performance, lower costs, and decrease the size of components, making MMW radar more attractive.

The main advantages of MMW radars are shown in Table 2. Their narrow beamwidth significantly enhances clutter rejection, and multipath effects, particularly if waveforms providing high range resolution are used. MMW radars will be used in short range applications such as low angle tracking where the ability to achieve narrow beamwidths with a small antenna is important. The high angular resolution, small size, and light weight of millimeter radars make them ideal for missile seekers in anti-armor weapons and terminal guidance. MMW radars are also useful in fire control and low-elevation tracking radars used in anti-aircraft weapons systems.

MMW radars have an inherent LPI feature in that atmospheric absorption imposes some limitations on the potential detection range of EW equipment, and narrow beamwidth restrict the detection space. The narrow beamwidth of MMW radar also reduces ECM vulnerability since injecting jamming energy into the antenna side lobes will be more difficult

Table 2: MMW Radar Advantages

1. Narrow Beamwidths with Small Apertures
2. Small Size and Lightweight Equipment
3. Can Have Large Bandwidth
4. Inherent LPI characteristic (Propagation loss, and narrow beamwidth)
5. High Resolution in Range, Angle, and Speed

3.5 Anti-tank missiles guidance

A considerable amount of research and development on seekers and fire control radars for tactical anti-armor weapons has been carried out. Many of these systems employ frequencies near 95 GHz since a small antenna suitable for an anti-armor missile or shell can provide adequate angular resolution for point targets. The greatest R&D effort in MMW radar has been the development of advanced seekers for anti-tank missiles. Typical MMW seekers are FMCW with a bandwidth of 500 MHz and a range resolution of 30 centimeters. This provides a range profile of the target making it possible to discriminate slow moving or stationary targets embedded in ground clutter. This is essential for anti-tank missiles, and would not be possible through Doppler processing. The radar signatures also make it possible to recognize the targets automatically. Radar target recognition based on high range resolution signatures is currently a key technology in development of anti-tank missile seekers. This significantly enhances the targeting capability of these missile systems against both line-of-sight and beyond visual range. These missiles will have a fire-and-forget, and post lock-on capability. This capability would be a big military advantage in future conflicts. These advanced anti-tank missiles will operate in the 35 GHz and 95 GHz MMW

windows. Deployment of such missiles can occur anytime now, for example, China claimed to have developed a prototype by 1990. To enhance survivability of our tanks, we should develop countermeasures as soon as possible against these new intelligent millimeter-wave missile seekers. Considering fifteen years into the future, the risk is expected to increase since China and India are researching MMW radars for guidance of missile systems.

3.6 Fire Control - Target Tracking

Many MMW radars primarily intended for the tracking of fast moving targets, such as aircraft or anti-ship missiles have already been developed. MMW radars have a better tolerance to multipath effects when the target being tracked is near the horizon. Russia is known to have significant capabilities in MMW technology and already uses MMW radars in battlefield surveillance, fire control and anti-aircraft missile systems.

3.7 Bistatic And Multistatic Radar

Bistatic principles are based on having a transmitting and at least one receiving antenna placed in different locations. There is now considerable research on development of multistatic radar throughout the world. Rapid advance in signal processing technology is critical to development of multistatic radar systems. Both Russia and China have been working extensively on development of bistatic and multistatic radars. Russia considers multistatic radar to be the next major development in radar technology. A forward-scatter fence type would be able to detect any targets, including stealth targets, crossing the border. The forward-scatter fence is not a new concept since the Japanese used it in WW2. However, the development of advanced computer technology and the threat posed by stealth technology has brought similar concepts back to life. China has published several papers on bistatic and multistatic radars. They have already tested a bistatic system using the JY-9 and JY-10 radars separated by 70 km. Aircrafts were successfully detected using this bistatic radar. Current development of bistatic and multistatic radars could represent a significant threat to our platforms.

3.8 Laser

Laser radar is a direct extension of conventional radar techniques to very short wavelengths. However, because they operate at much shorter wavelengths, laser radars are capable of higher accuracy and more precise resolution than microwave radars. On the other hand, laser systems are sensitive to the effects of the atmosphere and are thus generally restricted to shorter ranges in the lower atmosphere than microwave radar. Rather than supplanting microwave radar, laser radar opens new capabilities that exploit the great shift in wavelength, including [13]:

1. Tactical range and velocity imaging systems
2. Autonomous missile guidance
3. Precise aircraft navigation and guidance
4. Precision fire control

5. Remote atmospheric sensing

The use of lasers for radar applications will certainly be limited by atmospheric phenomenon. Due to the radar's operation at optical frequencies, capabilities are limited to daylight operation, and also to good weather conditions.

The compact size and the resolutions obtained using laser radars make their possible applications similar to MMW in many respects. A laser-based SAR onboard a UAV has already been demonstrated as feasible and collision avoidance systems for helicopters are currently being evaluated by the U.S. Army and others.

3.9 Over-The-Horizon Radar

High frequency (HF) operation has long been a favored transmission band for long-range, beyond line-of-sight communications and radar. HF systems operate in the 3-30 MHz frequency band At these frequencies, electromagnetic waves can be reflected on the ionosphere or follow the sea surface to propagate beyond the horizon.

Over-The-Horizon Radar (OTHR) is the only radar able to detect targets beyond the line-of-sight horizon. This capability significantly enhances both defensive and offensive operations. OTHRs are also a powerful counter-stealth sensor since they operate at frequencies where stealth technology is ineffective. This is why they are still the subjects of considerable attention worldwide.

OTHR can operate in two modes: sky-wave or surface-wave. In sky-wave mode, targets can be detected from 800 km to about 3500 km. Only a few nations have developed sky-wave OTHRs. U.S., Australia, France, Russia, Ukraine, and China. Sky-wave OTHR prohibitive cost will cool down the interest of others potential countries. Furthermore, they would not be practical to most countries since they cannot see anything within the first 800-km. The latest generation of sky-wave OTHR can be redeployed in a few days on a beforehand prepared site. This enhances their survivability and effectiveness since they can move in function of the perceived threat. Foreign development of sky-wave OTHR should continue to be closely monitored especially re-deployable OTHR.

The exploitation of surface-wave propagation allows tactical radar operating in the HF band to detect and classify low-flying or hovering helicopters, even when screened by terrain or dense foliage. HF equipment is readily available, and much less expensive than radars operating at microwave frequencies. ITT Avionics and Mirage Systems have collaboratively developed a HF radar that relies heavily on digital signal processing, using off-the-shelf hardware running reconfigurable software. Doppler processing removes the effect of ground clutter and measures the rotation rate of helicopter rotor blades. Bistatic operation, using expendable multiple receivers deployed throughout the battlefield, permits an accurate DF based on signal AOA measurement [14].

Surface-Wave OTHRs (SWOTHR) are emerging as a key technology for coastal defense and shipborne protection. They can detect any target between the ionosphere and the sea surface hundreds of kilometers away. In particular, they provide a significant increase in warning time of low-level threat targets, including stealth targets. Sea skimming missiles and low-level aerial attack are good examples of low-level high priority threats. SWOTHR will detect them at the earliest

moment when they are still hidden below the horizon. SWOTHR is an attractive solution for early warning. They provide wide area coverage and are an inexpensive substitute for airborne early warning systems.

Foreign deployment of SWOTHR can turn out to be a significant threat to western warships. Although SWOTHR is not very precise, it can provide OTH targeting data to long-range missiles. In future conflicts, the SWOTHRs might have to be destroyed before any coastal operation.

Significant efforts have been done worldwide to develop and field SWOTHRs. Several countries have already developed SWOTHR including U.S., U.K., Canada, Australia, Russia, and China. SWOTHRs fill a critical gap in low-level coverage along the coast, and could provide an OTH targeting capability for long-range missiles. These will have a strong impact on future maritime operations, especially in coastal area. Future operational scenarios will also have to take into consideration such capability.

China has started the design of a new type of VHF radar (probably 44 MHz) described as the *metric anti-stealth radar*. This system is based on the French RIAS (Radar à Impulsion et Antennes Synthétiques) radar concept. The RIAS radar is different from conventional radar on several points. It is a multistatic radar, that is, it uses different antenna for transmission and reception. This enhances its ECM resistance and survivability against anti-radiation missiles. The radar transmits omni-directional direct surface-wave pulses, and can detect targets out to several hundred kilometers. Although the illumination is omni-directional, the whole space is divided in small elements of volume, which receive a specific code through modulation techniques. When a target enters the space covered by the radar, the reflected echo contains information about the location of this target. By decoding the return pulses, the azimuth, elevation, and altitude are automatically known. This is quite an innovative idea, and makes this radar unique. The use of coding techniques makes it possible to use very weak VHF signals that are unlikely to be easily detected by airborne receivers. Further, there is no way of knowing that the RIAS radar is tracking a target since it does not scan. China could probably develop a prototype of RIAS radar after the year 2010. Successful development of this system would significantly enhance Chinese Air Defense capability.

4.0 DEPLOYMENT OF SYSTEMS

4.1 Ground-Based

Radar plays a major role in nearly every facet of modern warfare. Radars provide detection and targeting for weapons systems. Such radars can be found throughout the force structure, ranging from the infantry target ground surveillance radar to the most sophisticated radar system in the nose of a modern jet fighter. New applications, such as target acquisition systems for tanks to self-protection systems for armored vehicles, are being researched. These new systems may significantly impact future land warfare.

Air defense forces are the principal operators of radar systems on the modern battlefield. SAMs and AAA are in wide use by many forces throughout the world. They range from shoulder-launched SAMs to large-scale fixed missile complexes capable of engaging aircraft and/or ballistic missiles at very long ranges. SAMs developed 20 to 30 years ago are still prominent in worldwide military

inventories; however, newer systems are being widely developed and deployed to counter modern, higher performance threats.

Field artillery units must provide effective deep battle support at distances well beyond visual range. These engagements must often be made on modern mobile battlefields with only a very short time to engage a target before the target moves, or the firing artillery unit is detected and engaged by the enemy. The key to effective artillery fire support is the accuracy and effectiveness of first-round hits. These requirements dictate the need for the development and employment of accuracy enhancing sensors. Among the most important of these are radars such as muzzle velocity radars, shell trackers, weapons locating radars, and battlefield surveillance radars.

Most of the Russian ground radars are designed to be mobile or transportable, therefore providing the capability to relocate as desired. The ZOOPARK-1 weapons locating radar is a good example of Russian advanced radar technology. This system uses a phased array antenna integrated into the MT-LBu chassis. The radar antenna is a space-fed reflective phased array with a narrow beamwidth and low sidelobes. Frequency agility and pulse compression are also employed. Other examples of latest Russian radars include GAMMA D, CASTA, TALL KING, ZHUK, etc.

Russia has developed a large number of VHF radars and is known to have worked on a VHF Ballistic Missile Early Warning (BMEW) radar system. They describe the system as portable and able to detect satellites, ballistic missiles and stealth targets. Older BMEW radar systems required large antennas installed at fixed sites. The new Russian systems would increase their survivability significantly. Since early 1990's, Russia has also been advertising an advanced land-based phased array radar, called Summit, for the detection of space objects. This radar will operate in the millimeter band if ever deployed.

4.2 Weapons Locating And Shell Tracking

One of the main threats on the infantry is artillery. Artillery indirect fire weapons such as tube artillery, short and long range mortars and the increasingly popular multiple rocket launcher (MRL) all continue to increase in accuracy and lethality. Drawing on advanced technologies such as precise ballistic data, and terminal guidance, precision strike artillery can be directed at targets throughout the entire battlespace. A primary contributor to the improved accuracy of these weapon systems has been the development of a group of radars referred to as shell trackers and weapons locating radars (WLR). Shell trackers provide friendly fire registration by tracking outbound rounds and calculating trajectory errors, which can be used to correct the firing data of follow on rounds. Many of these systems can provide fire correction before the first round actually impacts on the target[1].

WLRs provide the locations of targets for counterbattery fire by monitoring the battlefield for incoming rounds, and tracking their trajectories. From the incoming trajectory data, the location of the firing point can be calculated, and used to provide targeting data on the firing point. These types of radars are some of the most sophisticated systems in use today throughout the world. They have

---

[1]A popular technique is to fire a registration round at a secondary target, compute the trajectory error, and apply the correction for fire on the primary target.

been designed to meet extraordinary detection criteria, such as detecting an object with a radar cross section of 0.1 m^2 moving at supersonic speeds in the presence of other flying objects. Compounding this challenge is the need to maintain a track on the object for a sufficient amount of time to calculate its point of origin.

A revolution in the use of WLRs occurred with the development by the U.S. Army of the AN/TPQ-36/37 *FIREFINDER*[2] family of radars. Using state-of-the-art technology of the late 1970's, these radars incorporated phased array antennas and Doppler processing to accomplish multiple target tracking. The *FIREFINDER*s have become one of the most highly exported radar systems in the world with many countries currently operating them. Among the users of the *FIREFINDER* systems are PRC, Israel, Jordan, and Saudi Arabia.

4.3 Battlefield Surveillance

Battlefield surveillance radars will continue to be important on future battlefields. They provide a target acquisition capability for indirect fire weapon systems. These radar systems are designed to detect formations of men as well as moving vehicles. The proliferation of these systems is widespread. The radars come in diverse forms, and vary from highly compact manpack versions to track and vehicles mounted variants.

Modern systems include the French *RASIT* and *STENTOR*, the German *RATAC*, the Bulgarian HP-100, the Russian 1RL136 and RP-200, and the U.S. AN/PPS-15. These systems use Doppler processing to detect small moving targets in a clutter background. Vehicle-mounted systems are predominantly Russian in origin. The BIG FRED and SMALL FRED are examples of this class of systems. Most Western systems such as the Dutch *SQUIRE* FMCW radar can be either manportable or vehicle-mounted. *SQUIRE* uses MTD processing to detect infantry at ranges up to 10 km and moving vehicles out to 25 km.

Most of these surveillance radars operate in the I/J-bands with some in the MMW bands. Some operate at low peak powers. Other factors that add to their survivability are high mobility, remote operation, and tactics, which take advantage of natural terrain features for detection masking. Typical detection ranges for these systems are roughly 10-15 km for moving personnel, and 25-30 km for a moving vehicle. Some radars also have a secondary mode for helicopter detection as well as a mode for explosion detection, which can be used for cursory artillery fire correction.

Modern battlefield surveillance radars have become an integral part of the artillery target acquisition process. They are used in consorts with the WLRs and shell tracking radars to increase weapon accuracy and to improve sensors to shooter reaction times. Ongoing work will continue to make these radars harder to detect which will increase their ability to classify and identify targets. This class of radars should be considered a significant threat on any future battlefield.

---

[2]Manufacturer nicknames or project names will be italicized so that they may be easily discerned from NATO nicknames.

4.4 Meteorological

Meteorological radars have long been a necessity on the battlefield for obtaining atmospheric information to program into ballistic calculations for artillery, free-flight rockets, and ballistic missiles. This information is still required and will be required in the future, but attempts are being made to obtain this information from other sources, such as weather satellites, civilian facilities, etc to maintain operational security. Another factor affecting the need for these radars is the employment of fire correction radars. While fire-correcting radars cannot be used with ballistic missiles, their actual tracking of artillery and free-flight rockets eliminates the need for the weather radar information.

The elimination of these radars from a military inventory would serve to increase operational security, which is severely jeopardized by the emissions from these radars. It is widely known that observation of these emissions can be used as an indicator for imminent indirect fire missions. If other sources of atmospheric data prove to be fruitless for battlefield purposes, then every attempt to make these radars as undetectable as possible will be undertaken.

4.5 Surface-To-Air Weapons [15]

4.5.1 Heavy IR SAM

The SA-13 is an Eastern Block weapon of this type. It has an integral range-only radar (Russian name ZEE) which is intended for automatic determination of the target position relative to the limits of the missile launch envelope. The system also calculates the initial lead angle for the launcher before firing. This radar was incorporated in the system to reduce the chances of a missile launch while the target was still outside the system's engagement envelope [16].

Although IR SAMs do not require tracking or missile guidance radars, most of them have integral surveillance radar as part of the system for target detection during autonomous operation. One example is the use of the DOG EAR surveillance radar with the SA-13. The addition of a range-only radar such as the ZEE on the SA-13 could become commonplace. These radars will probably operate at MMW frequencies and only transmit for short periods. Short operational times will make them extremely difficult to detect and locate.

4.5.2 Short-Range SAMs

Mobile SAMs with ranges of 5-12 km are increasing in sophistication. Often mounted on tracked vehicles, but sometimes on transportable shelters, these are probably the most important anti-aircraft weapons in a modern army.

The first system in this class to enter development was probably the British *RAPIER*. This radar has proved attractive on the export market. *RAPIER 2000* has a steerable opto-electronic tracker in place of the surveillance radar fitted to current systems. This version operates in conjunction with trailer-mounted *DAGGER* 3-D radar.

The Tracked *RAPIER* system was sold to the British Army only. A new private-venture *RAPIER LASERFIRE* may find its way into the export market. The system has two major features which

should make it attractive: 1) compact size, and 2) the laser and MMW emitters do not excite traditional RWRs covering 2-18 GHz, nor do they provide a homing signal for current ARMs.

In its basic form, the French *CROTALE* has been sold to Chile, Egypt, France, Greece, Libya, Pakistan, South Africa, and the United Arab Emirates. The first of the upgrade versions, designated the *SHAHINE*, was designed for Saudi Arabia and delivered in the early 1980's.

The *CROTALE NG* (New Generation) is based on the VT-1, a Mach 3.5 wingless missile. The system has a turret equipped with the surveillance and tracking radars, plus a FLIR and TV camera. The missile maneuvers in response to signals from the narrow-beam, frequency agile command link. *CROTALE NG* is being delivered to Finland. The version adopted by the Netherlands uses the *VARIBEAM* surveillance radar developed by Signaal.

The surveillance radar for the *CROTALE NG* is the *GERFAUT* TRS 2630. The radar operates in E/F-band and employs a phased array antenna for 3-D coverage. The radar is advertised as having the following EP features: 1) low antenna sidelobes, 2) wide transmission bandwidth, 3) digital pulse compression, 4) dual-frequency change receiver, 5) velocity filtering, and 6) false alarm regulation [17].

The German *ROLAND* has enjoyed similar success to *CROTALE* and is deployed in several variants. On an AMX-30 tank chassis, it serves with France, Iraq, Nigeria, Qatar, and Spain. German Army systems are mounted on the *MARDER* armored fighting vehicle (AFV), a combination also selected by Brazil. Argentina and Venezuela have adopted shelter-mounted versions. In 1990, an international consortium teamed to create a 12-16 km range Mach 5 version of the *C* for use with an improved fire-unit designated RM5. Deliveries should begin in 1996-97.

The surveillance and tracking radars associated with the *CROTALE* and *ROLAND* are very similar in their transmission characteristics. The surveillance radars for both operate in the E/F-band with nominal antenna rotation rates of 60 RPM. The tracking radars operate in J/K-band and have maximum tracking ranges of 16-17 km. The *ROLAND* tracking radar is advertised to employ frequency agility. While details of the *CROTALE* tracking radar are sketchy, this radar probably has this capability as well [18].

The former Soviet equivalent of *CROTALE* and *ROLAND* is the SA-8 GECKO. Developed by the Antey bureau, the system has been exported to Algeria, Angola, Czechoslovakia, former East Germany, Guinea, Guinea-Bissau, Hungary, India, Iraq, Jordan, Kuwait, Libya, Poland, Syria, and Yugoslavia. Radars associated with SA-8 are the LAND ROLL series that comprises an H-band surveillance radar, a J-band tracking radar, and two I-band missile command uplinks [19].

The follow-on to this system is the same organization's *TOR* system, known to NATO as the SA-15. This is a G/H-band, pulsed Doppler, pulse compression, surveillance radar mounted at the rear of a turret with full 360° coverage through its maximum engagement range of 25 km. Those targets that represent the highest threat are assigned to either a 25 km-range J-band phased array tracking radar which can track two targets simultaneously, or a back up TV tracker with a maximum good weather range of 20 km. Command guidance is used, and the missile can intercept targets at heights ranging from 10 to 600 m [20].

China's only equivalent to the *CROTALE* and *ROLAND* is the FM-80. Unlike the European systems, it is not mobile and is currently offered only in a shelter-mounted form. In physical appearance it seems identical to the French shelter-mounted *CROTALE*, although with a different surveillance radar. The FM-80 has completed development and is in production for the PLA (People's Liberation Army). It is available for export.

In creating its *TANSAM*, adopted for service in 1980, Japan used a very different technology. Target detection is accomplished using a phased array radar. A pre-programmed autopilot guides the missile, with passive IR terminal homing. However, if the radar is jammed or if the targets are at a very low altitude, a tripod-mounted electro-optical sight can be used to track the incoming target. Early in 1981, a contract covering initial R&D on an improved *TANSAM KAI* was issued. Progress has been slow and full-scale development could run through the mid-1990s. The new missile is expected to have strap-down, mid-course guidance, and an active seeker that can be locked-on after the launch.

India is developing a truck-mounted SAM with a maximum range of 9 km. The acquisition and tracking radar appear to be a modified Dutch *FLYCATCHER* I and K-band radar which the Indians have a license to produce. Known as the *TRACHEAL*, the system probably uses radar-based command to line-of-sight guidance. Trials began in 1987 and production should begin in the mid 1990s.

4.5.3 Medium-Range SAMs

Just as light heat-seeking air-to-air missiles can form the basis of a SAM system, so can heavier semi-active radar weapons in the class of the *SPARROW*. Italy's *ASPIDE* is a *SPARROW* derivative. A single battery was delivered to the Thai Air Force in 1988.

Like the *SPARROW*, China's HQ-61 is a semi-active radar guided weapons fielded in landbased and naval versions. The army version uses a truck-mounted launcher and Model 571 C-band radar for target acquisition[3].

The U.S. *Improved HAWK (I-HAWK)* and SA-3 GOA are both serving in large numbers around the world. Since the *I-HAWK* entered service in 1972, many modifications and product improvements have been made to the system. These include adding MTI to the pulsed acquisition radar, deleting the range-only radar, and incorporating a digital signal processing capability into most aspects of the system.

A foreign-based modification of the *I-HAWK* is the *NOAH* (Norwegian Advanced Hawk). The batteries include *I-HAWK* launchers, the *HAWK* High-Power Illuminator (HPI) and a U.S. built TPQ-36A[4]. The follow-on *NASAMS* (Norwegian Advanced SAM System), due to have entered service

---

[3]The Model 571 appears to be a Chinese copy of the former Soviet FLAT FACE radar.

[4]The TPQ-36A is an air surveillance variant of the AN/TPQ-36 mortar locating radar of the *FIREFINDER* series.

in 1994, combines the target acquisition system with surface-launched *AMRAAM* missiles. The system has been offered to the U.K. (known as *AdSAMS*) as a replacement for the *BLOODHOUND* missile system which was withdrawn from service in 1991.

The former Soviet SA-3 is still in service with some twenty-five export customers, but a more important role is played by another veteran system, the SA-6 GAINFUL

The replacement for the SA-6 in former Soviet service is the SA-11 GADFLY. The deployment pattern is similar to that of the older system, with all vehicles using a tracked chassis. Each launch vehicle has its own FIRE DOME tracking radar. The SA-11 is to be replaced in the mid-1990s by the SA-X-17 GRIZZLY, which started development in the early 1980s.

The main feature of the SA-X-17 is the introduction of new engagement radar called CHAIR BACK that replaces the FIRE DOME. The SNOW DRIFT surveillance radar accomplishes target acquisition. This was the same radar used in the SA-11 [21].

China's new KS-1 medium SAM is probably in the same performance class as the SA-3. The KS-1 uses radar-based command guidance. System development is almost complete and the KS-1 may be close to entering production.

India's *AKASH* medium-range SAM operates with the *RAJENDRA* phased array radar, and probably uses radar command to line-of-sight guidance. The system is still undergoing development and will probably enter service in the late 1990s to early 2000s.

The *RAJENDRA* is a multifunction engagement radar composed of a 4000 element phased array antenna advertised to employ pulse compression and MTI processing. The radar provides all the required radar functions required by the *AKASH* SAM system to include target acquisition, tracking, and missile guidance [22].

4.5.4 Long-Range SAM/ATBM Systems

For engagements at long range, a heavy SAM such as the former Soviet SA-2 can be used. Today's armies, however, need something more portable and accurate to cope with modern threats. The U.S. *PATRIOT* is an example of this new portable class of SAM, with its revolutionary Track-Via-Missile (TVM) guidance system. Many limitations discovered in the Gulf War led to several product improvement modifications resulting in the current PAC-3 *ERINT* system. The *ERINT* missile is a hit-to-kill type employing an onboard active seeker to improve kill probability [23].

The *PATRIOT* system is designed around a large multi-function phased array G-band engagement radar. This radar performs the entire sensor functions for the system to include target acquisition, tracking, and missile guidance.

Taiwan's *TIEN KUNG I (SKY BOW)* closely resembles the *PATRIOT* except that the TVM guidance technology was not transferred so that the *TIEN KUNG I* relies on two indigenously developed seekers.

The nearest former Soviet equivalent to *PATRIOT* is the SA-10 GRUMBLE. Guidance is TVM and the launchers and the FLAP LID phased array radar are carried on an eight-wheeled vehicle, while

a trailer houses the 36D6 3-D surveillance radar [24].

An improved version of the SA-10 system, designated the S-300PMU-1 by the Russians, has been developed and was shown at the IDEX' 93 defense exposition in Abu Dhabi. The system was to have become operational in Russian Air Defense forces in late 1993

The Eurosam consortium is tackling development of a European heavy SAM able to replace the I-HAWK. Known as *SAMP/T*, the system is based on the *ASTER 30* vertically launched missiles and frequency-agile I-band multi-function phased array radar called the *ARABEL*. If they require coverage of near vertically diving attacks, a French TRM 160-11 *ZENITH* radar can be added. This electronically scanned UHF radar set will complement the coverage of the main radar. Development testing of the *SAMP/T* is not due to end until 1997.

The SA-12A/B GLADIATOR/GIANT (Russian designator S-300V) is the only operational SAM system in the world which was designed from the outset as an Anti-Tactical Ballistic Missile (ATBM) system. The system consists of the TELAR with integral target illumination and missile guidance radar, a C^3 vehicle, a BILLBOARD 3-D surveillance radar, a HIGH SCREEN 3-D sector scanning radar, and the GRILL PAN multi-function phased array engagement radar. Initial target detection by the BILLBOARD can be achieved at ranges up to 250 km with the GRILL PAN able to detect and track targets out to 150 km [25].

A joint U.S.-Israeli project is now underway to develop a true ATBM system for Western use. The system, called *ARROW*, comprises a high velocity interceptor missile being developed in the U.S., and a multifunction target engagement radar being developed by the Israelis. The system is still undergoing testing. Current plans call for the radar and missile systems to be integrated sometime in 1995. The system will probably not enter service until the late 1990s [26].

4.5.5 Anti-Aircraft Artillery

AAA has long been a mainstay in ground forces air defense. AAA systems can be sub-categorized into self propelled and towed gun systems. Self propelled or SPAAGs are becoming increasingly popular due to their inherent mobility. Towed gun systems have long been used for static site defense, but they are becoming obsolete on today's dynamic battlefields where mobility is the key to survivability.

Technology insertion and operational upgrades are maintaining combat effectiveness of many older SPAAGs. In the West, the U.S. Army has applied many product improvements to the *VULCAN* air defense system. Radar related improvements include a digital computer linked to the range-only radar to provide more accurate lead and super elevation.

Production of the former Soviet ZSU-23-4 has probably ended in 1983, but some upgrading of the GUN DISH radar and fire control system has probably taken place since the end of production. The GUN DISH operated in J-band with a frequency range of 14.6-15.6 GHz [27].

A new arrival in the SPAAG market is the ZA-35 air defense system developed in South Africa. The system includes an EDR 110 targets detection radar that operates in D-band and is credited with a detection range of 12 km for fixed-wing aircraft and 6 km for rotor craft. Target tracking is

accomplished using the ETR 1100 MMW radar, which is said to incorporate many EP features [28].

Few dedicated systems are built, especially from the radar aspect, which are limited to solely AAA. The two predominant Western manufactured radars for towed AAA are the Swiss manufactured *SKYGUARD*, which is licensed to Brazil and the Dutch-built *FLYCATCHER* licensed to India. These systems are similar in characteristics in that both have I-band target acquisition radars and dual-band tracking radars operating in I and K-band (MMW). These systems are deployed throughout the world and can be integrated with many different calibers of guns.

Through Soviet Union military sales, there is now a proliferation of systems, such as 37 mm, 57 mm, and 130 mm guns and their associated fire control radars such as FLAP WHEEL and FIRE CAN to nearly every continent in the world.

Countries such as China, and probably North Korea as well, has continuously modified and enhanced these AAA systems incorporating new technology to keep these systems current. China has long been known for providing cheap, functional equipment and will probably keep the market alive for AAA systems for many years to come.

4.5.6 Hybrid Systems

A recent trend in army air defense has been the integration of guns and missiles into a single vehicle or system. The best known Western system of this type is probably the Swiss-built *SKYGUARD*. Several nations have adopted *SKYGUARD*, each giving it a local designation.

System 390 is an integrated gun/missile-based air defense system that has been developed by the Chinese. Seeker sensitivity allows all-aspect engagements out to ranges of 10 km.

Egypt has selected the hybrid *SINAI* system that is based on the M113 APC. The system can be fitted with either an IR night vision system, or a French RA-20S surveillance radar.

An impressive gun/missile system is the former Soviet Army's 2S6.

4.6 Air Surveillance

A discussion of all the current and projected air surveillance radar systems is beyond the scope of this paper. This is due principally to the large number of these systems in use worldwide, many of which are quite similar in terms of performance and operating characteristics. Instead, we address some emerging trends, which will have the greatest impact on military forces from a threat perspective. This trend analysis has focused on the introduction of 3-D radars for long-range, medium-range, and short-range applications, Doppler processing for short-range applications and developments to detect low-observable aircraft.

Advanced 3-D radars are increasingly playing a major role in long-range and medium-range air surveillance applications. Nearly all-modern radars of this type employ phased array antennas. Frequency scanning in elevation using frequency sensitive array is a popular technique used in modern 3-D radars, but will probably diminish in the future, being completely replaced by electronically scanned phased array systems. Being capable of maintaining hundreds of simultaneous target tracks is common for modern phased array air surveillance radar.

Some examples of long-range air surveillance systems are the U.S. manufactured *VSTAR* and *HADR*, the French TRS2230/2215 and TRS 22XX, the German TRM-S, the Italian RAT-31S, the British AR-3D, and the Japanese NPG-880. These systems are large, fixed-site, strategic-type radars which most Third World countries cannot afford or do not require for adequate early warning of airborne targets. Russian systems such as the VHF-based TALL KING, Type 55G6-1, Type 1013-3, SPOON REST, and the 3-D TIN SHIELD have been exported throughout the world and will probably remain a mainstay of many countries for many years to come.

Medium-range surveillance radars qualify as many countries' long-range systems, since most of these countries' territorial coverage is less than that of a state in the U.S.. Radars which fall into this category are the French *TIGER S/G*, the Russian BIG BIRD, BILLBOARD, and SNOW DRIFT, the Chinese JY-9 and 146-1, and the South African ESR-360. There is more of a mix in the antenna technologies in this category; however, as with the long-range systems, phased arrays will probably become the technology of choice. Older systems such as the Russian LONG TRACK, which uses multiple beams for elevation determination, will continue to survive for several years to come until they either become obsolete or simply too expensive to maintain.

Modern long-range and medium-range systems rely on pulse compression and digital MTI or MTD processing to achieve the processing gain needed to detect targets at ranges more than 250 km in the presence of heavy clutter and EA. Most operate in D and/or E/F-band and have fairly slow update rates. The slow update rates are due to the need for extended time-on-target requirements for long-range detection.

Short-range or tactical surveillance systems (sometimes called short-range target acquisition) are probably the most numerous radar systems in the inventory of most modern armies. They usually have a detection range of less than 100 km, have fast update rates (1-4 seconds), and employ Doppler processing for direct measurement of target radial velocity and improved detection in clutter. These radars must be highly accurate for direct cueing of fire-unit target acquisition and tracking radars. This means that these radars must operate at higher frequencies to achieve greater gain using antennas, which are sufficiently small for tactical systems.

Radars which fall into this category are the Swedish *GIRAFFE* and *HARD*, the Chinese *IBIS* and Type 706, the Russian DOG EAR, the French *RAC*, the Dutch *REPORTER* and *SKYSPY*, the South African ESR-220, and the Polish N-22. These radars usually support short-range weapons' systems. Their antennas are normally placed on elevated pedestals to enhance low-altitude detection. Most of these radars have an advanced Doppler-processing mode for detecting hovering helicopters.

The *HARD* radar, whose parameters are summarized in Table 3 is a primary example of how this class of advanced air surveillance radars is developing. The 3-D coherent pulse Doppler radar is advertised as having excellent LPI characteristics. It employs techniques such as frequency agility over a bandwidth of 500 MHz, low antenna sidelobes, low peak power through the use of digital pulse compression, and narrow beamwidth through phase scanning using a phased array. *HARD*, which has an instrumented range of 20 km, can be used in the stand-alone air surveillance role, or integrated into a weapon system as its target acquisition radar.

Now, most of these radar antennas are not advanced arrays. A trend could easily develop toward

arrays if their costs come down. Short-range systems can employ effective EP measures since they are employed closest to the enemy throughout the battlespace. Their proximity to the enemy renders them the most vulnerable to effective EA.

The use of stealthy aircraft raises significant concerns in the international radar community. There is recognition of the need to develop radar systems quickly, which could detect these low observable aircraft. To this end, one major area being investigated is the use of low operating frequency radars. Stealth technology cannot defeat all radars operating in all frequency bands, so that technology was designed to defeat radars which are the highest threat to fixed-wing aircraft. This threat is the microwave frequency of SAM and AAA radars.

Russian radars such as TALL KING, and some of their newer VHF radars operating in the 160 - 180 MHz range have been advertised as providing good detection capabilities against low-observable aircraft. The lower frequency with its longer wavelength is said to be able to detect stealth aircraft. For that reason, the West has begun to return to radar development in the VHF band over the last ten years, but Russia is still regarded as the world leader in this technology. However, if more countries deploy stealthy aircraft, we may see a significant increase in development of radars to detect them [29].

Table 3: HARD Parametric Characteristics

Instrumented Range	1 - 12 km 1.5 - 20 km
Elevation Coverage	0 - 35°
Antenna Revolution Rate	40 RPM
Antenna Gain	32 dBi
Beamwidth - azimuth - elevation	 3.0° 5.5°
Sidelobe Level	-6 dB
Frequency Band	8.8 - 9.3 GHz
Output Power - peak - average	 65 W 8 W
Duty Factor	13 %
Pulse Duration	13/21 μsec
Sub-pulse Length	1 μsec
PRF	1 MHz

4.7 Ground Vehicle Self-Protection

Many research projects are currently underway throughout the world to develop methods to protect main battle tanks. A self-protection being investigated is the *TAMS* (Tank Anti-Missile System) being tested in the U.K. as a proof-of-concept project. The system is a small self-contained turret that mounts a surveillance radar, an automatic fire control system and twin guns. It is designed to provide automatic point defense for armored vehicles. It detects, tracks, and destroys anti-tank missiles without needing to be alerted, aimed, or fired by the tank crew. The hostile missiles can be of any type: wire-guided, laser-guided, laser-guided, radar-guided, heat seeking, side or top-attack, or even terminally guided munitions [30].

TAMS's surveillance radar operates in the 35 GHz frequency band, and is based on technology developed for the DN181 *BLINDFIRE* radar for the *RAPIER* missile. *TAMS's* fire control system uses a version of the MMW radar seeker in the *BRIMSTONE* missile operating at 94 GHz. The current status of this system is unknown, but it does illustrate that research is being conducted in this area and that these types of systems could emerge as future threats [31].

4.8 Target Acquisition Systems For Main Battle Tanks

One area of current MMW research is in the development of a target acquisition and engagement system for main battle tanks (MBT). The research is being driven by the requirement for all-weather target acquisition and engagement capabilities, an area in which current MBT optical systems are severely limited. A radar that was being developed for the U.S. Army in the 1980s was known as the *STARTLE* (Surveillance and Target Acquisition Radar for Tank Location and Engagement). Some preliminary specifications for this representative type radar are presented in Table 4. The radar was intended to complement, and be integrated with, the IR thermal tank sight such that both systems shared the same display. Spread spectrum waveforms and both coherent MTI and area MTI techniques were being investigated for detection of moving targets. The radar incorporated a solid-state IMPATT (IMPact ionization Avalanche Transit Time) diode transmitter power source [32].

Table 4: STARTLE Specifications

Frequency	94 GHz
Average Power	0.1 - 0.5 W
Antenna Aperture	35.6 cm
Field-of-view (Scan sector)	Frequency
Frame Time	> 2 sec.
Target Detection	3000 m with 100 m visibility

Apparently, problems were experienced with the 94 GHz application. It has since given way to a

new project called the MTI Ground Radar. This radar is planned to incorporate as much new technology as feasible while attempting to use many components from existing radar programs The operating frequency has been lowered to 35 GHz because of unacceptable attenuation in rain at 94 GHz. Current plans call for the incorporation of DDS technology for pulse compression waveform generation, a MIMIC transceiver, and as many COTS components as possible to achieve a high performance radar at the lowest cost [32].

4.9 Subsurface Object Detection

Most ground probing radars (GPR) are based on ultra-wideband impulse radar technology. Many applications for GPR technology are being developed for commercial applications, but the primary military interest is subsurface anti-tank and anti-personnel mine detection. Typical parameters of a GPR are presented in Table 5 [33].

Table 5: Typical GPR Parametric

Pulse Duration	1 ns
Pulse Type	Impulse or Monocycle
Peak Power	50 W
PRF	1 MHz

4.10 Airborne

4.10.1 Battlefield Surveillance

Airborne surveillance radars can be mounted on virtually any platform dictated by the desired depth of coverage, the element being supported, and the time-on-station required. Current platforms include fixed-wing aircraft such as the U.S. Joint Surveillance and Target Attack Radar System (JSTARS), fighter aircraft such as the Israeli F-4-mounted AN/APG-76, rotorcraft as in the French *HORIZON*, and more recently UAVs.

Airborne surveillance radars can be grouped into two major categories, SAR and MTI. Some fixed-wing systems can employ both techniques. SARs are susceptible to EA, but MTI radars can employ fairly agile parameters that allow for some degree of protection from deception and corruption.

The JSTARS ground surveillance radar can interleave SAR and MTI modes. It is elevated mechanically and steered electronically in azimuth to provide deep looks into enemy territory. The deep looks give early warning of secondary troop movements and buildups.

These surveillance systems are strategic in nature. This will probably limit their use to countries of major military stature. One interesting possibility in this area would be the development of these systems for commercial applications, much like commercial satellite imagery. The value of the commercial information they can provide to countries or threat elements that cannot afford to operate their own surveillance systems cannot be overlooked. These systems must be considered a potential

threat not only in a full-scale war against a major power, but also in low-intensity-conflict (LIC) environments, and other-than-war-situations.

The fire control radars in several types of combat aircraft already incorporate a SAR mode that assists in mapping, target acquisition and weapons delivery. During the Gulf War, US F-15s received imagery in flight from *JSTARS* and were able to correlate it with that from their own onboard AN/APG-70. Other SAR-equipped combat aircraft [34] include the F/A-18C/D carrying the AN/APG-73, the B-1B bomber with the AN/APQ-164, and the B-2 bomber with the AN/APQ-181.

The upgraded F-4 aircraft used by the Israeli Defense Force incorporates an AN/APG-76 Multi-Mode Radar System (MMRS). The AN/APG-76 has a specified range of thirty-five nautical miles but has routinely produced SAR maps at ranges up to 100 nautical miles.

An example of a rotorcraft mounted system is the French *HORIZON* system's *TARGET* radar. This radar is a coherent pulse Doppler, I/J-band system with a detection range of approximately 100 km. For EP purposes and enhanced performance in clutter, a low sidelobe antenna is used. The system is not designed to be a stand-alone system, but to complement longer range systems such as *JSTARS*. The system is also highly susceptible to air defense weapons and is primarily used after air superiority has been established. Other parameters associated with the *TARGET* radar are (1) a wide frequency band transmitter, (2) fast frequency agility, (3) digital pulse compression, and (4) an adaptive burst mode.

According to the French, they can provide a *TARGET* derivative that is 40% lighter and more compact, making it suitable for smaller helicopters. A system similar to the *TARGET* is the Italian *FIAR CRESO* I/J-band pulse Doppler radar. The commonality of the two systems is that the radar data is transmitted via a data link to a ground processing van, where it can be integrated with other sensor data.

UAVs offer a different twist to the airborne surveillance mission. At the present, several countries are researching the feasibility of mounting surveillance radars on these platforms. An example of a UAV-mounted radar is the Lockheed Sanders *SLAM-R*. This pulse Doppler radar employs MTI techniques and is primarily used for gathering tactical information with a maximum detection range of 17.5 km. *SLAM-R* operates in J-band (16.0 - 16.5 GHz) and can employ frequency agility over its transmitter bandwidth of 500 MHz. The radar can provide 360 degrees of coverage with accuracy on the ground of 50 meters CEP (Circular Error Probability).

Other projects currently ongoing in this area are the U.S. TIER II medium altitude endurance (MAE) UAV, and the Israeli *HERON*. The MAE prototype is to be equipped with a Westinghouse J-band SAR that has an 800 meters wide swathe out to a distance of 11.2 km, with a maximum resolution of 0.3 meters.

These radars will probably become a major threat in any battlefield environment. Rotorcraft and UAV systems will probably be more attractive to countries that have smaller forces, and lower capital investment budget. They will be used extensively by all forces in the next century.

5.0 CONCLUSIONS

This report seeks to predict the radar technology and the techniques that will be deployed by potential adversaries. It intends to provide support to the Canadian Army in defining components of the future land electronic warfare threat. It shows that radar will remain the prime sensor for air defense systems but will become more integrated with other sensors and other radar bands. Radar performance will continue to increase rapidly over the next decade and will include the following characteristics:

- The ability to detect stealthy targets in the presence of intense ECM.
- Enhanced high and low altitude coverage.
- Increased multi-functional abilities.
- Deeper integration with other sensors.
- Use of advanced processing techniques.
- Faster response times.
- Increase automation of many functions.
- Enhanced identification capability.

6.0 LIST OF ABBREVIATIONS

Acronym	*Definition*
AI	Airborne Intercept
AJ	Anti-Jam
AAA	Anti-Aircraft Artillery
AFV	Armored Fighting Vehicle
ARM	Anti-Radiation Missile
ATBM	Anti-Tactical Ballistic Missile
BMEW	Ballistic Missile Early Warning
BPSK	Binary Phase Shift Keying
CEP	Circular Error Probability or Circular Equivalent Probability
CFA	Cross Field Amplifiers
CIS	Commonwealth of Independent States
DDS	Direct Digital Synthesis
DF	Direction Finding
EA	Electronic Attack
ECM	Electronic Countermeasures
EP	Electronic Protection, formerly Electronic Counter-Counter Measures (ECCM)
ESM	Electronic Support Measures
EW	Electronic Warfare
FA	Frequency Agility
FLIR	Forward Looking Infra-Red
FMOP	Frequency-Modulation-On-the-Pulse
FOV	Field-Of-View
GPR	Ground Penetrating Radar
GW	Giga Watts (i.e. 10^9 Watts)
HF	High Frequency
HPI	High-Power Illuminator
HPM	High-Power Microwave
IEW	Intelligence and Electronic Warfare
IMPATT	IMPact ionization Avalanche Transit Time
LIC	Low-Intensity-Conflict
LPAR	Large Phased Array Radar
LPE	Low Probability of Exploitation
LPI	Low Probability of Intercept
LRS	Linear Recursive Sequences
MAE	Medium Altitude Endurance
MBT	Main Battle Tank
MHz	Mega Hertz (i.e. 1 million Hertz or 10^6 Hertz)
MMW	Millimeter Wave
MRL	Multiple Rocket Launcher

MTI	Moving Target Indicator
MTD	Moving Target Detection
ns	nanosecond
OTHR	Over-The-Horizon Radar
PLA	Peoples Liberation Army
pps	pulse per second
ps	pico second (i.e. 10^{-12} second)
QPSK	Quaternary PSK
RESM	Radar Electronic Support Measures
RIAS	Radar Impulse Aperture System
RPM	Rotations Per Minute
SAR	Synthetic Aperture Radar
SAM	Surface-to-Air Missile
SPAAG	Self Propelled Anti-Aircraft Gun
SSPR	Super-Short Pulse Radar
TTD	True-Time Delay
TVM	Track-Via-Missile
TWT	Traveling Wave Tube
UAVs	Unmanned Aerial Vehicles
UWB	Ultra-WideBand
WLR	Weapons Locating Radars
WW2	World War Two

7.0 REFERENCES

1. *Jane's Radar and EW Systems*, 1993-1994, pp. 248.

2. Durrant, R and Parkes, S.M. (1991), The implementation of high time-bandwidth chirp using digital techniques, *IEE Colloquium on High Time-Bandwidth Product Waveforms in Radar and Sonar*, May 1, IEE Digest

3. Elmer, F.J, Ward, R. and Frederickson, G. (Apr. 1996), *Radar technology 2010: military IEW challenges.*

4. Newberg, I.L. and Wooldridge, J.J. (1993), Revolutionary active array radar using solid state modules and fiber-optic, *Record of the 1993 IEEE National Radar Conference*

5. Osipov, M.L. (1995), Superwide-Band Radar, *Telecommunications and Radio Engineering*, 49(9), pp. 42-47.

6. Ganz, M.W., Smith, J.K.(1996), Russian microwave capabilities: a firsthand report, *Proceeding of the 1996 IEEE Aerospace Applications Conference.*

7. Herskovitz, D. (Sept. 1995), Wide wider widest, *Microwave Journal*, pp. 26-40

8. Birx, D., Fishback J.R. (1992), High power 10 KHz repetition rate UWB source development at the US Army's missile command, *IEEE MTT-S Digest, pp. 1605-1608.*

9. Oicles, J., Staskus, M., Brunemeier (1994), P., High-power impulse generators for UWB applications, *Second International Conference on UWB Short-Pulse Electromagnetics.*

10. Gabanov, V.P., Korovin (Jul. 1994), S.D., etc, Generation of high-power nanosecond pulses of electromagnetic radiation, *Tech Phys Lett*, 20(7), pp. 604-605.

11. Yalandin, M. I., Shpak, V.G. (1995), etc, Compact repetitive generator of high-power broadband electromagnetic pulses, *SPIE*, Vol. 2557, pp 289-297.

12. Immoreev, I., Vovshin, B. (1995), Features of UWB radar projecting, *IEEE International radar conference, pp. 720-725.*

13. Jelalian, A.V.(1992), *Laser radar systems*, Artech House Inc.

14. Hewish, M. (June 1994), Low-level air defense: new sensors enhance effectiveness, *International Defense Review.*

15. Richardson, D.(1991), Air defense for land forces, *Defense*, September.

16. Defense Products from Russia, Advertising supplements to *Military Technology, Feb. 1993.*

17. *Jane's Radar and EW Systems, 1993-1994*, pp. 111-112.

18. Ibid., pp. 110-112.

19. Selected Soviet SAMs, *Jane's Soviet Intelligence Review*, 1991 January.

20. SHORAD Supreme: The *TOR* SAM system, *Military Technology, Dec 1993.*

21. The *URAL* (SA-17 GRIZZLY) air defense missile system, *Jane's Intelligence Review POINTER, Dec. 1993.*

22. Brochure, *RAJENDRA:* Multifunction electronic scanning phased array radar, Electronics and Radar Development Establishment, DRDO, 1997.

23. Keller J. (1994), U.S. throttles up on theater missile, *Military & Aerospace Electronics,* December 1994.

24. The S-300PMU-1 air defense/ATBM SAM system, *Military Technology, Nov. 1993.*

25. S-300V: The ATBM trendsletter, *Military Technology*, August, Aug. 1993.

26. Hewish M.and Starr, B. (June 1994), Catching the bullet: theater missile defense faces realities, *International Defense Review.*

27. *Jane's Radar and EW Systems, 1993-1994, pp.* 101-102.

28. *Jane's Radar and EW Systems, 1993-1994,* pp. 125-126

29. Russia selling stealth radar, *Associated Pres,s 1994.*

30. *Jane's Radar and EW Systems, 1993-1994,* pp. 133.

31. Reedy, E.K., and Wiltse J.C. (1988), Fundamentals of MMW radar systems, *Aspects of Modern Radar,* Artech House.

32. Mollica, S., Wilson, T. and Adler, E. (1995), MTI ground radar, *Proceedings of the AOC Second Radar/EW Conference, 22-23 Feb. 1995.*

33. Daniels, D.J.(Dec. 1994), Surface penetrating radar for industrial and security applications, *Microwave Journal.*

34. Hewish, M. (Jan. 1995), Airborne ground surveillance: new technologies meet urgent demands, *International Defense Review.*

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document Organizations for whom the document was prepared, e g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8)

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

2 SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title)

RADAR TECHNOLOGY FORECAST FOR LAND WARFARE (U)

4 AUTHORS (Last name, first name, middle initial)

FARLEY, GUY, J., AND GAUTHIER, S.M.

5 DATE OF PUBLICATION (month and year of publication of document)	6a. NO. OF PAGES (total containing information Include Annexes, Appendices, etc.)	6b. NO OF REFS (total cited in document)
APRIL 2000	40	34

7 DESCRIPTIVE NOTES (the category of the document, e g. technical report, technical note or memorandum. If appropriate, enter the type of report, e g interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

DREO TECHNICAL MEMORANDUM

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address)

DREO

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written Please specify whether project or grant)	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)
PROJECT 2KE11	

10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity This number must be unique to this document.)	10b. OTHER DOCUMENT NOS (Any other numbers which may be assigned this document either by the originator or by the sponsor)
DREO TECHNICAL MEMORANDUM 2000-064	

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12 DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

13 ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual)

(U) The Canadian Army is planning a major update of land electronic warfare equipment in the next few years. In support of this acquisition there is a need to define the radar component of the future land electronic warfare threat. Part of the definition process involves predicting the technical characteristics of the array of radars that will be deployed by potential opponents. This report documents the predicted radar technical characteristics. It has been written as one input to the Land Electronic Warfare Threat Target Array Study being coordinated by J2 Scientific and Technical Intelligence and sponsored by the Director of Land Requirements (DLR) and the Director of Land Command Systems Program Management (DLCSPM). After considering the future trends in radar technologies and systems, this report also reviews the deployment of radar systems that are relevant to future land warfare. That section is divided into two parts: the ground-based and the airborne systems. When possible we give the following radar information: name, capability, specification, time of availability, the list of the countries developing and acquiring it. Out of the ground-based radar, we specifically consider the following: weapons locating and shell tracking, battlefield surveillance, meteorological surface-to-air weapons, ground vehicle self-protection, target acquisition systems for main battle tanks, and subsurface object detection.

14 KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

RADAR
TECHNOLOGY
FORECAST
LAND

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM